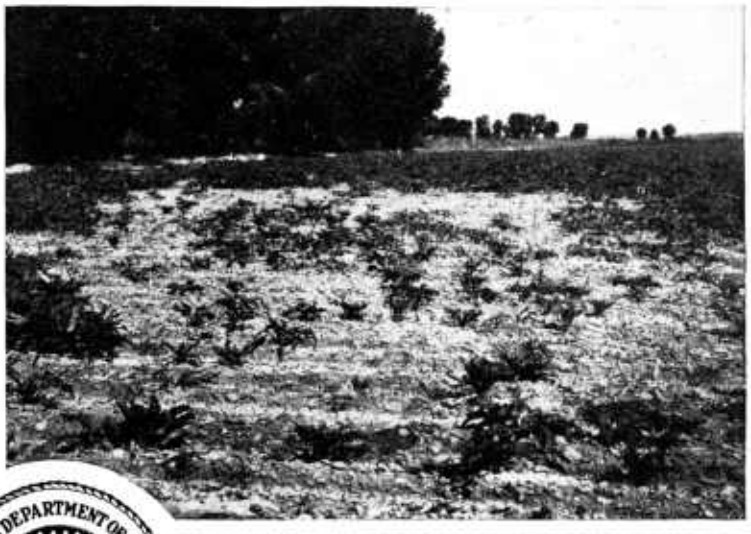
U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1514

CONTROL OF SUGAR-BEET NEMATODE *by* CROP ROTATION



THE SUGAR-BEET NEMATODE is established in practically every important beet-growing section of the western half of the United States. In some sections its control is one of the major problems confronting the beet-sugar industry. In other western sections, if effective control methods are neglected, the nematode doubtless will soon become equally serious.

This nematode is found only in sections where sugar beets have been grown for many consecutive years without crop rotation, enabling the pest to become well established and widely distributed over the fields.

Practical control is now effected in some of the worst infested areas by practicing crop rotation. In some of the newly infested districts the spread of the pest is being checked by the elimination of infested fields from beet culture and the rotation of crops on the fields as yet free from infestation.

This bulletin summarizes the results of several years of field investigations of the sugar-beet nematode in the Western States. After a brief discussion of the present known distribution of the nematode, its life history, common sources of infestation, and host plants, practical methods of control are outlined. The data on control derived from actual field results will enable the beet growers and sugar companies to formulate plans to reduce to a minimum the losses from this pest.

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CONTROL OF SUGAR-BEET NEMATODE BY CROP ROTATION

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DISTRIBUTION OF THE NEMATODE

THE SUGAR-BEET NEMATODE[1] has been known to be present in the United States for about 35 years. During this time new infestations have developed in such numbers and old infested areas have so increased in size that in many sections the control of the pest now ranks as one of the major problems confronting the beet-sugar industry. The accompanying map (fig. 1) shows the present known distribution of the nematode. These widespread infestations indicate that eventually every important beet-growing section in the Western States will probably become infested. The States west of the Mississippi River are in greater danger of serious infestation because beets often are grown on the same land for many successive years, a practice that fortunately is not common in the Central States.

The degree of infestation in the various States is as follows:[2]

California.—The principal beet-growing areas adjacent to the following places are generally infested: Betteravia, Chino, Los Alamitos, Los Angeles, Oxnard, Santa Ana, and Spreckels. A few fields are known to be infested near Alvarado, Lompoc, Pleasanton, Stockton, and Woodland.

Colorado.—The most severely infested areas lie in the Arkansas Valley between Pueblo and the Kansas line, especially near Vineland, St. Charles Mesa, Manzanola, Rocky Ford, Sugar City, Avondale, and Swink. In the northern part of the State a considerable number of infested fields occur in the areas tributary to the beet-sugar factories at Eaton, Greeley, Windsor, Loveland, Longmont, Brighton, Fort Lupton, and Fort Collins. On the west slope a few fields are infested near Delta and Grand Junction.

Idaho.—In the vicinities of Sugar and Preston the fields are generally infested. Near Idaho Falls, Rigby, Shelley, Blackfoot, Paul, Rupert and Burley a few fields are known to be infested.

[1] *Heterodera schachtii* Schmidt.

[2] The writer is indebted to officials of the sugar companies operating in the various States for data on nematode distribution in 1940.

Montana.—A considerable number of infested fields are known near Billings.

Nebraska.—Areas adjacent to Bayard, Gering, Lyman, Minatare, Mitchell, and Scottsbluff have many infested fields.

Utah.—Sugar-beet nematode has become a limiting factor in the beet acreage that can be grown in Cache, Salt Lake, Utah, and Weber Counties, while in Box Elder, Davis, Sanpete, and Sevier Counties it has become established in a large portion of the fields.

Wyoming.—A few fields are infested near Torrington and Wheatland.

LIFE HISTORY OF THE NEMATODE

The form of the sugar-beet nematode commonly seen in the field is the female, which appears as a small, milky-white, lemon-shaped

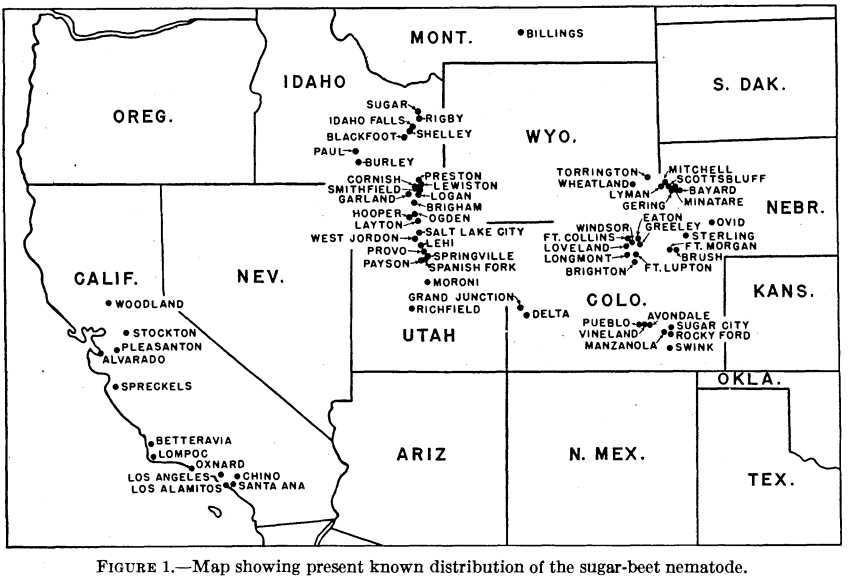

FIGURE 1.—Map showing present known distribution of the sugar-beet nematode.

body clinging to the beet root (fig. 2). Practically speaking, the female is a mass of from 100 to 600 nematode eggs (fig. 3). From these eggs hatch small, slender worms or larvae which average one-sixtieth of an inch in length (fig. 3). They are equipped with a strong spearlike organ in the mouth (fig. 4), with which they make an entrance into the beet root. Here they feed on the plant juices and soon molt.

Up to the time of molting there is no visible difference in the sexes, but afterwards there is little similarity. The males remain long and slender, somewhat like the larvae, except that they are several times as large and have blunt rounded tails (fig. 5). After maturing they break from the roots and go in search of the females.

After molting, the females are flask-shaped. As their size increases they break through the root tissues and remain attached by their heads. At this stage they are fertilized by the males and soon develop into lemon-shaped bodies. A gelatinous fluid is excreted, which collects in a mass about the posterior end. Into this mass many of the females deposit eggs, which soon hatch, the larvae finding their way into the soil or into the beet. The number of eggs deposited varies from a few to upward of a hundred, and since several generations occur each season there are soon enormous numbers capable of attacking the beets (fig. 6).

FIGURE 2.—Nematode-infested sugar beet. The small white bodies on the roots are female nematodes. (Actual size.)

As the season advances, many of the females change in color from white to dark brown, assuming what is commonly known as the brown-cyst or preservation form. In this form the dead body of the female serves as a protecting sac for the eggs, many of which may become dormant. If sugar beets or other favorable host plants are grown the following year, most if not all of these eggs hatch. However, if no host plants are present, only a few of the larvae hatch, the remainder lying dormant in the eggs. This condi-

tion may prevail for several years. Just how long is not known definitely, but a few remain at the end of 5 or 6 years.[3]

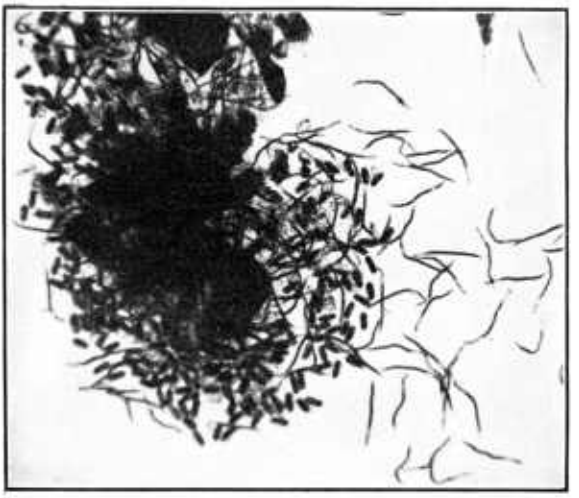

FIGURE 3.—Cyst form of the sugar-beet nematode which has been crushed in order to show the eggs and larvae. (Magnified 25 times.)

HOW TO DETERMINE NEMATODE INFESTATION

The first evidence of nematode injury commonly noticed is the appearance of small areas in the field which produce no beets or only a few undersized ones (fig. 7). Unless a considerable quantity of infested soil has been hauled into the field, it is usually 2 or 3 years after infestation before these areas are large enough to attract attention. On severely infested areas the beets wilt and wither away just after thinning, often only a few remaining. These do not make such rapid growth as those outside the infested area. If the infestation is only slight or moderate and if the moisture and cultural conditions are favorable for growth, the beets may not die but simply make less growth than normal beets. As the season advances the infested beets will be found to wilt much more readily on warm days.

If one of these infested beets is carefully dug up, it will be found small and stunted, with many more small roots than the normal beets have (fig. 8). In some instances the entire taproot is covered with these small roots, many of them being brown and dead. If nematodes are present, an examination will usually reveal the small, lemon-shaped, white bodies of the females clinging to the roots. Later in the season they are often found on the beet itself. At this

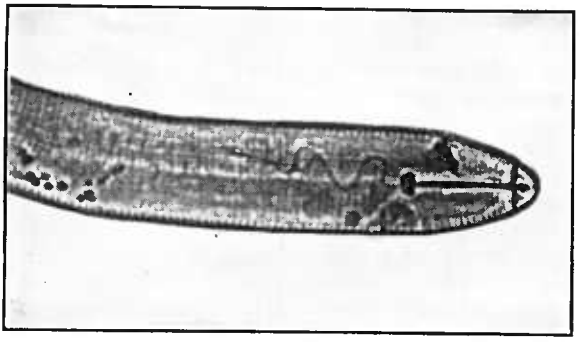

FIGURE 4.—Head of larva of the sugar-beet nematode, showing the spear with which it works its way into the beet root. (Magnified 1,000 times.)

[3] THORNE, GERALD. LENGTH OF THE DORMANCY PERIOD OF THE SUGAR-BEET NEMATODE IN UTAH. U. S. Dept. Agr. Cir. 262, 5 pp. 1923.

time it will probably be noticed that many of them are becoming brown—the development of the brown-cyst stage. These visible forms of the nematode are not able to move at all, and the observer should not confuse them with the sugar-beet aphis,[4] which is a true insect several times as large as the nematode and which can be seen to move about slowly. These aphids are commonly found in dry spots in the field where the beets resemble somewhat those infested with nematodes.

Occasionally it is very difficult to find the nematodes on the beets even in severely infested fields. This condition usually prevails in fields that are very dry, the nematodes having died from lack of moisture. Careful examination of such fields will sometimes reveal some of the brown cysts attached to the roots, but it is usually necessary to make a soil test, as described in the next paragraph.

It is possible to determine whether suspected areas are infested even if beets are not growing on the land, as in the winter or when other crops are planted. This is best done by taking a small quantity of soil, preferably dry, from the suspected areas and dropping it into a glass of water. If considerable numbers of nematodes are present, some of the brown cysts will immediately rise to the surface, where they gather on the glass and appear as small, lemon-shaped, bright-brown bodies that are easily distinguished from the black weed seeds and other rubbish with which they may be associated. For one not accustomed to their

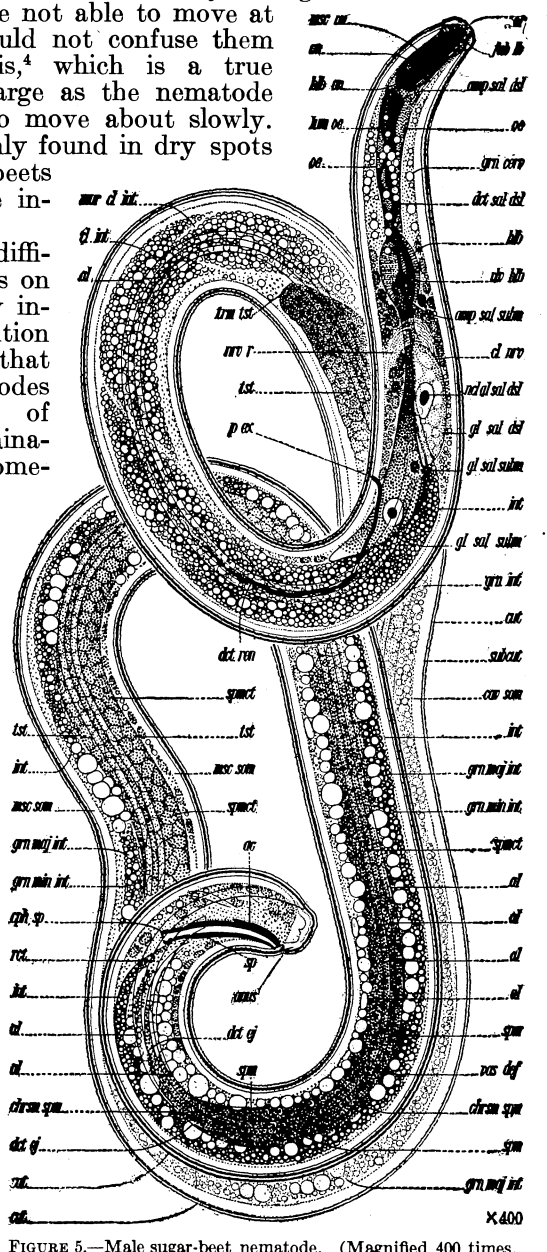

FIGURE 5.—Male sugar-beet nematode. (Magnified 400 times. After Cobb.)

[4] *Pemphigus betae* Doane.

appearance it may be difficult to be certain of them, and a small hand lens will be of service in identification.

Beets infested with nematodes appear to be more susceptible to leaf spot, phoma, and other leaf diseases, because of their weakened condition. For this reason diseases are sometimes assumed to be the cause of inferior growth when the actual primary cause is nematode injury to the roots. In the Arkansas Valley in Colorado, the presence of small areas of leaf spot in the fields was often found to be associated with nematodes, and because of the leaf spot the infestation was overlooked for several years.

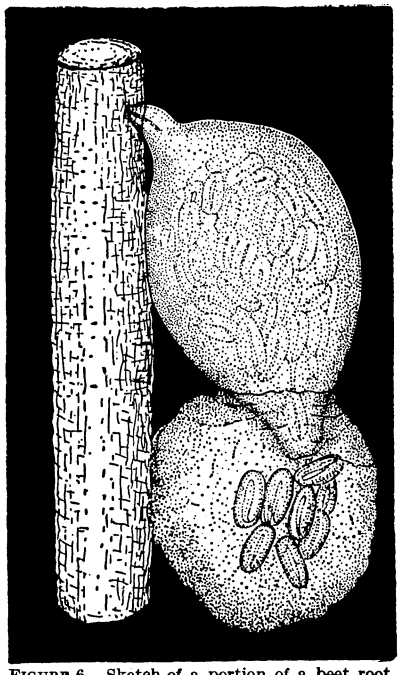

FIGURE 6.—Sketch of a portion of a beet root, showing attached female nematode with egg sac containing eggs. Some females deposit no eggs, whereas others produce upward of 100. (Magnified 30 times.)

Other causes which produce an appearance similar to that of nematode injury are alkali spots in the soil, attacks of the garden or root-knot nematode,[5] excessive moisture, and dry spots. In fact, it is absolutely necessary to make a careful examination of the beet roots or of the soil and find the nematodes before their presence can be known for a certainty.

SOURCE OF INFESTATION

The sources of sugar-beet nematode infestations in the United States are not definitely known. The nematode is a native of Utah, where it lives on shadscale, a desert shrub.[6] It may also have come from Europe in dirt mixed with beet seed. The brown cysts filled with eggs are carried in this manner, and from them colonies of nematodes become established when the cysts are planted with the seed.[7]

After becoming established in a field the nematodes are spread over it in many ways. Farm implements, especially cultivators, levelers, and harrows, drag particles of soil containing the nematodes from the infested areas and scatter them in other parts of the field. Irrigation water running over infested soil picks up the cysts and larvae and deposits them along the furrows, where new colonies are soon established. Often the infested area in a field is only 3 or 4 rods wide and several times as long, following the course of irrigation and cultivation (fig. 9). Livestock trampling over a wet field may carry cysts in the mud on their feet and thus transfer the nematodes to other parts of the field. It is doubtful if the natural migration of the nematodes themselves will carry them more than a rod in a season, therefore these other agencies are those that should be considered in preventing their spread.

[5] *Heterodera marioni* (Cornu) Goodey.
[6] *Atriplex confertifolia* (Torr. and Frem.) S. Wats.
[7] Charles Price, associate agronomist, Division of Sugar Plant Investigations, has obtained evidence of the existence of live nematodes in dirt picked from imported seed. (Verbal communication.)

From farm to farm the nematodes are carried by machinery, livestock, irrigation water, or any other agency that will transport the infested soil from one place to another. Scattering of dump dirt from farm to farm doubtless has been chiefly responsible for the rapid increase in nematode infestations. The prevalent practice of a trucker contracting to haul the beets of several growers is rapidly infesting those fields that still remain clean. Truckers rarely have any interest other than hauling the beets in the shortest possible time and unload the dump dirt indiscriminately, regardless of the fact that it may carry

FIGURE 7.—Typical recently infested area only three or four rows wide. Many of the infested beets were killed just after thinning time, whereas those a few feet away were uninjured. The following year this spot increased to three times the area shown here.

nematodes from infested to clean fields. Dump dirt should be placed in holes, swamps, or other waste places whenever it is possible to do so.

HOST PLANTS OF THE NEMATODE

A knowledge of the host plants of the sugar-beet nematode is essential when planning crop rotations for its control. Fortunately the nematode is restricted to a few of the common crops and a small number of weeds. This makes it a comparatively simple matter to select a rotation which will effectively reduce the nematode population in any field.

The following lists of susceptible plants represent the results of hundreds of examinations of the various crops in all of the States in which the sugar-beet nematode has been found:

Field crops.—The only crops found infested besides sugar beets are mangel-wurzel, table beet, cabbage, cauliflower, rape, turnip, rutabaga, and radish. If any of these are planted on heavily infested soil the plants often are attacked severely and the yield reduced (fig. 10). At the same time such crops enable the nematodes to increase in numbers until it is impossible to grow a successful crop of beets following them.

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Weeds.—Mustards (*Brassica* spp.), lambsquarters (*Chenopodium* spp.), and saltbush (*Atriplex* spp.) are common host plants of the sugar-beet nematode and are an important factor in carrying it over in the field from year to year. Knotweed (*Polygonum minimum*), dock (*Rumex* spp.), redroot (*Amaranthus retroflexus*), and purslane (*Portulaca oleracea*) also are occasionally found infested. Therefore, clean cultivation must be practiced during a rotation or these weeds may counteract much of the value of rotation by furnishing food for the nematodes.

In Europe some crops, including peas, oats, and potatoes, and in Hawaii sugarcane, which are not listed here as host plants, have been reported as susceptible to the sugar-beet nematode. As such infestations have not been found in the United States, however, it may doubtless be safely assumed that they either do not exist in this country or are very rare and limited in their distribution.

FIGURE 8.—Beets from a field in which the crop was a complete failure because of severe nematode infestation. (About one-third actual size.)

GENERAL CONTROL METHODS

PREVENTION OF INFESTATION

Noticeable infestation with the sugar-beet nematode is found only in fields that have produced many crops of sugar beets with little or no rotation. Throughout the Western States it is not unusual for a field to have grown beets almost continuously for 10 to 25 years. This condition is ideal for the establishing and rapid increase of nematode colonies, should a few nematodes chance to reach the field through dump dirt, irrigation water, or in any other manner.

From the point of view of possible nematode infestations, it is therefore of the utmost importance that a crop-rotation system be adopted for uninfested fields, where sugar beets shall be grown not more than 3 years in succession. Under such a system of crop rotation, if nematodes should be introduced into the field they probably would not be able to increase in numbers sufficiently to cause perceptible damage.

ELIMINATION OF SMALL INFESTED AREAS

Often small infested areas can be planted with other crops, leaving the remainder of the field for sugar beets. A thick stand of alfalfa is especially useful for this purpose because there is less danger of

spreading the infestation than there is if cultivated crops are planted and, at the same time, it will keep down weed hosts. When areas are segregated in this manner, an allowance of 2 or 3 rods on each side of the infested area should be made, as the nematodes are always distributed farther than is indicated by the severely injured beets.

PRACTICAL CONTROL BY CROP ROTATION

A successful rotation is one that will give reasonable returns for labor and investment and at the same time increase, if possible, the productivity of the soil. In planning a rotation the following points

FIGURE 9.—Beets on land severely infested with nematodes following 1 year of barley. This field well illustrates how nematode infestation is spread in the direction of irrigation and cultivation.

must be considered: Severity of the infestation, profitable crops adapted to the field, and general fertility of the soil.

ROTATION ADAPTED TO SEVERITY OF INFESTATION

The degree of infestation may be divided for convenience into three classes—light, moderate, and severe.

Light infestation includes those fields in which the injury is confined to one or more small areas which form only a small percentage of the total acreage. Light infestations may be controlled by rotations of only 1 or 2 years, 2 years being preferable, as alternating years in beets may allow the nematodes to increase until the field would be classed as moderately infested. As crops for such rotation, peas, beans, white sweetclover, potatoes, tomatoes, or other cultivated crops may be used. Wheat, oats, and barley are less desirable, especially because of the weed hosts that they frequently harbor. Where convenient, the leguminous crop should precede the sugar beets.

Moderately infested fields may have affected areas 2 or 3 rods in extent, causing a loss of 10 to 20 percent of the crop. Moderate infestations should have rotations of 2 or 3 years, and in these the crops listed for use with light infestations should be chosen (fig. 11). Another excellent plan is to reduce the infestation to a light condition by 3 or 4 years of alfalfa, after which a crop of beets may be grown every third year.

Severely infested fields are those in which one-fourth or more of the crop has been destroyed, and these require a rotation of not less than 3 and preferably 4 or 5 years. For this long rotation the most common crop used is alfalfa, but if desired the rotation may be made

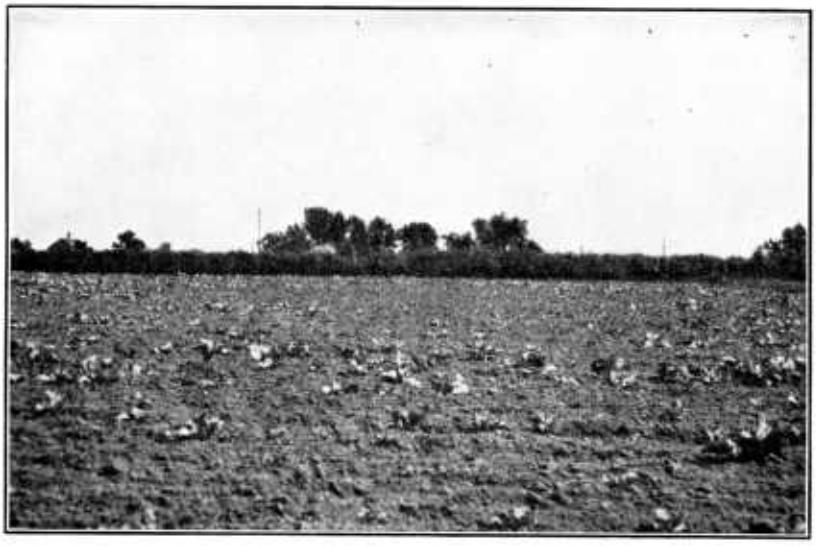

FIGURE 10.—A cabbage field severely injured by nematodes.

up of 1 or 2 years of small grains, followed by 2 or 3 years of potatoes, peas, or beans. A 4- or 5-year rotation commonly reduces the infestation so that beets may be grown profitably every third year. Alternate cropping with beets is inadvisable even after rotations of 5 to 8 years.

Under any system of rotation careful watch must be kept, and if serious nematode injury appears the length of the interval from beet crop to beet crop must be increased.

ROTATION VALUE OF CROPS IN NEMATODE CONTROL[8]

Alfalfa.—So far as is known, alfalfa is not attacked by the sugar-beet nematode, and as it usually remains for 3 or more years after seeding, it has become the most popular crop for rotations covering 3 or more years. A good stand is essential because weeds will grow in spaces between plants, and on these the nematodes may live over from year to year. Examination of soil from alfalfa fields 6 to 12

[8] The reader is referred to the following circular for detailed crop rotation information under California conditions: ROBBINS, W. W., and PRICE, CHARLES. SUGAR-BEET PRODUCTION IN CALIFORNIA. Calif. Agr. Col. Ext. Cir. 95.

years old has shown that the only nematodes remaining are in the spaces between plants where weeds have grown. Because alfalfa usually begins to thin out about the fourth or fifth year in most fields it should not be allowed to remain longer, as the weeds that come in serve as host plants for the nematodes. After 4 or more years most of the nematodes have hatched out and died, but invariably a few live over so that it is apparently impossible to eradicate them completely (fig. 12).

Usually it is not advisable to follow the alfalfa immediately with sugar beets, as many growers find difficulty in obtaining a good

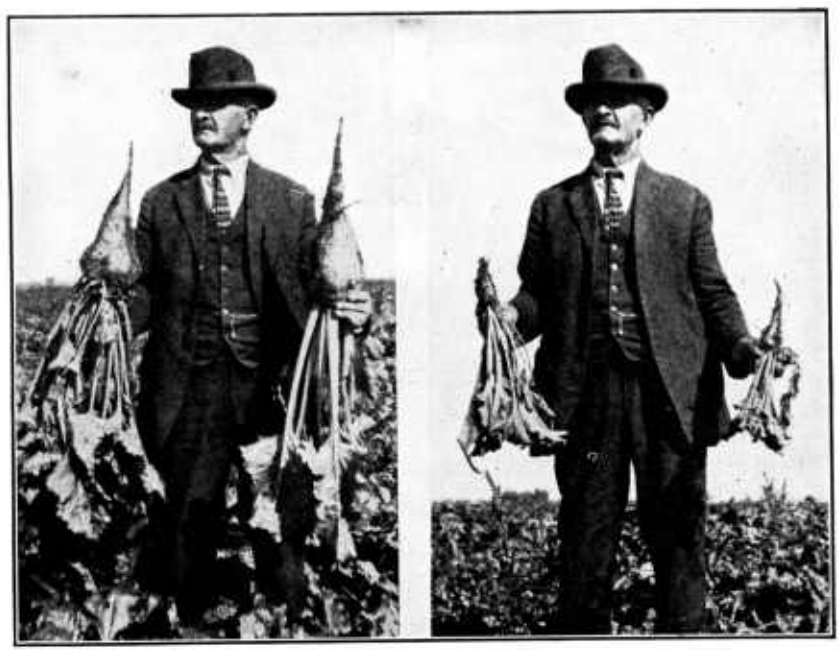

FIGURE 11.—Result of rotation on moderately infested field. During the 2 years following the one in which this field produced 12 tons to the acre and had many small areas infested, half of the field was rotated with potatoes and oats, and the other half was kept planted with beets. The year following the rotated portion produced 22 tons to the acre, whereas the unrotated part was almost a failure. The beets shown were taken within 10 feet of each other, those on the left from the rotated portion and the others from the unrotated.

crop, probably because of the fact that it is difficult to get a good seedbed. If the seedbed is not good the young beets fail to get a good start in the spring and are more susceptible to the attacks of nematodes, damping-off, and other diseases. Most growers prefer to follow the alfalfa with a crop of potatoes, tomatoes, grain, or corn, which puts the soil in much better condition for the crop of beets following. Potatoes and other cultivated crops are especially good and give better results than the small grains.

Fields 50 and 51 of table 1 illustrate this fact. After becoming severely infested with nematodes, the fields were sown with wheat and alfalfa, and the alfalfa was plowed up at the end of 3 years. One field was planted with potatoes, the other with wheat, and both were followed by beets the next year. The field in which beets followed potatoes gave a yield of 18 tons to the acre, whereas that in

which beets followed wheat produced only 12 tons. Although the difference may not always be so great as this, it is usually very noticeable in any field where the effects of cultivated and grain crops upon the subsequent beet crop can be compared. This difference doubtless is due to the fact that the cultivated crops leave the soil in better tilth than do the grain crops. Then, too, barnyard manure may be applied after the alfalfa on the fields where cultivated crops are grown, and this contributes to the productiveness of the soil the following year.

As a green-manure crop, alfalfa ranks high. When used in this manner, generally the first or last crop of the season is plowed under.

FIGURE 12.—A 16-ton crop of beets following a 4-year alfalfa rotation. The stand and yield were apparently about normal, but a few nematodes were present on every beet by harvesttime.

When the alfalfa is turned under in the spring, it is usually followed by a crop of corn or potatoes. When the alfalfa is large, the decaying organic matter doubtless kills considerable numbers of nematodes.

Sweetclover.—This leguminous crop is used generally and gives excellent satisfaction as a hay, pasture, and green-manure crop. When a heavy crop is plowed under, the heat and gases of the decaying material kill large numbers of the nematodes, including those within the brown cysts. Examination of soil from such fields showed that the numbers killed varied from about 5 to as many as 22 percent of the nematodes.

Sweetclover is not a host plant of the sugar-beet nematode and therefore fits in well for short rotations on slightly or moderately infested fields. It is especially valuable on poorly drained or alkaline soils where alfalfa does not thrive.

Beans.—As the bean is not a host of the sugar-beet nematode and is a legume, this crop is suitable to include in any rotation. One

crop of beans on slightly infested fields usually will be followed by a good crop of beets. Placing one or two bean crops at the end of 3- or 4-year rotations is a successful practice on severely infested land, especially in the great beet- and bean-producing sections of California.

Peas.—Like beans, peas are an excellent leguminous crop to fit into any rotation in sections where they are grown in commercial quantities. As they are harvested early in the season, an opportunity is given to plow the land and allow it to lie fallow the remainder of the year, thereby keeping down weeds and putting the soil in good condition for the following crop of sugar beets.

Potatoes.—Potatoes are perhaps the most popular cultivated crop used in rotations and give excellent results either in a 1-year rotation on slightly infested fields or when included in longer rotations. They are especially good as a crop to precede sugar beets after long rotations of alfalfa. After a crop of potatoes the soil is in excellent tilth, which is of importance in providing a proper seedbed for the sugar beets following. Then, too, barnyard manure is often used with the potato crop, and this also benefits the following beet crop.

Wheat.—Wheat has proved to be one of the poorest crops to use in short rotations. Sugar beets grown after 1 or 2 years of wheat rarely yield more than before the rotation, even when barnyard manure is applied (fig. 13). It is usually grown as the nurse crop for alfalfa—a very successful practice, and one or two crops may be included in longer rotations, provided that some leguminous or cultivated crop precedes the sugar beets. Wheat is not a host of the sugar-beet nematode, but very often weeds, such as mustards and lambsquarters, grow abundantly in wheat fields and furnish food for the nematodes.

Barley.—Although not a host plant for the sugar-beet nematode, barley ranks no better in rotations than does wheat. It may be used in long rotations, but rarely gives successful results in 1- or 2-year rotations.

Oats.—This crop has been reported in Europe as susceptible to attack by the sugar-beet nematode, but careful examinations of oats grown on more than 30 severely infested fields have failed to reveal a single instance of susceptibility. It seems safe to assume, therefore, that the oat is not a common host plant under the conditions here dealt with. In short rotations it gives no better results than wheat and barley, but it may be included in longer rotations.

Corn.—This is a good crop to use in any rotation but does not seem so desirable as the leguminous crops or potatoes. The stubble often creates some difficulties in drilling and cultivating a following beet crop.

Tomatoes.—The tomato is not a host plant of the sugar-beet nematode and can be grown successfully in either short or long rotations. As a crop preceding beets, it usually gives good results.

Truck or garden crops.—Because of the high soil fertility maintained in truck gardening, many of the crops grown make excellent rotations on nematode-infested land. Onions are especially good. However, the following should never be planted on infested soil: Cabbage, cauliflower, table beets, mangel-wurzels, turnips, rutabagas, and radishes. These are host plants of the sugar-beet nematode and very often are damaged severely.

VALUE OF FERTILIZERS IN NEMATODE CONTROL

The production of a successful beet crop depends upon how well the soil fertility is maintained. With nematodes present, fertility is even more imperative, for if the beets do not make an immediate, thrifty growth from the beginning of the season, a comparatively small number of nematodes will so check growth that the yield may be seriously reduced. However, if the young beets grow thriftily, they will not be injured perceptibly by the nematodes even though they are present in considerable numbers.

Barnyard manure generally is the principal fertilizer applied, and in sections where farms are small and livestock are kept it has been pos-

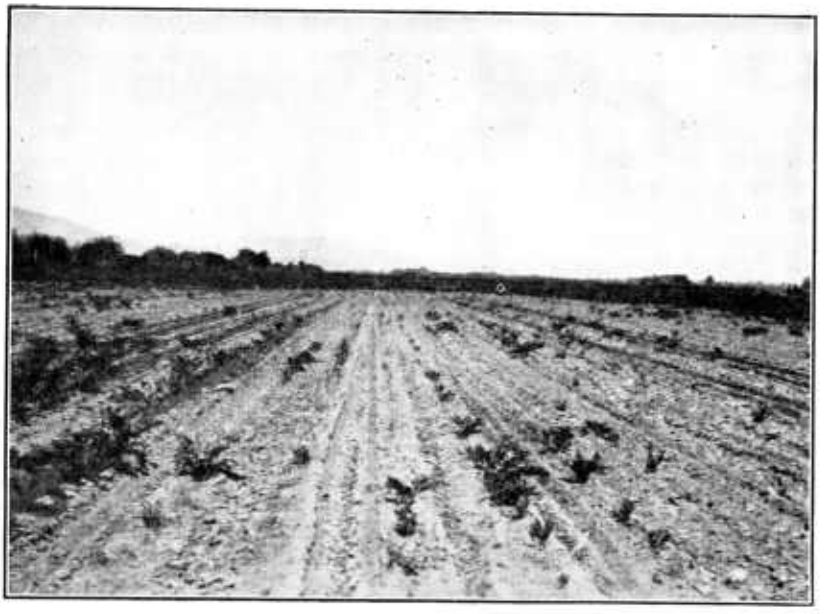

FIGURE 13.—Typical result of attempting a crop of beets on severely infested soil after 1 year of wheat. The infested areas are a total loss.

sible to maintain a normal beet production through its use, except in those localities where phosphate deficiency occurs.

Green manures are becoming more popular, and some sections must rely upon them almost entirely, since it is impossible to obtain sufficient quantities of barnyard manure. Sweetclover and alfalfa are used most commonly for green manure and give good satisfaction when plowed under properly. Excellent results have been obtained with them on some fields severely infested with the sugar-beet nematode.

Commercial fertilizers, especially superphosphate, are coming into more general use and in certain localities are almost essential to insure a normal beet crop. However, on nematode-infested fields they must be used in connection with the regular crop rotations, otherwise their value will largely be lost, for they do not reduce the nematode population.

BENEFITS OF EARLY PLANTING

Planting as early as the season will permit is advisable, regardless of whether or not the field is infested with sugar-beet nematodes. The young beets get a better start and are better able to withstand the attacks of nematodes, insects, and diseases that may appear later in the season.

This is especially true with regard to fields infested with sugar-beet nematodes, even though the field has been given a suitable rotation. Early in the season a small number of the larvae will hatch and emerge from the brown cysts, and unless the young beets are fairly well established, there is some danger of their growth being checked.

RESULTS OF VARIOUS CROP ROTATIONS

Table 1 gives the results obtained from various crop rotations under actual field practice. All of these fields were severely infested with the sugar-beet nematode. However, there is a considerable difference in the degree of infestation, varying from fields on which the crop was a total loss to those from which a yield of 12 or 14 tons was produced. These latter fields usually had large areas on which the beets were free of nematodes or but slightly infested.

Practically all of these fields are located in Utah and represent the better class of soils, which, under ordinary conditions, produce from 14 to 25 tons of sugar beets to the acre. In nearly all instances barnyard manure in varying quantities was applied before the beet crop. On many of the fields it had been applied on preceding crops of potatoes, tomatoes, etc.

The reader should remember that on slightly and moderately infested fields the 1- and 2-year rotations will give better results than they did on these severely infested fields.

The figures on tonnage were obtained partly from growers and partly from sugar-company records. There may be some errors in the yields given for fields before the crop rotations, because of lack of written records on many fields. In such instances the figures on yields have been obtained from estimates of the tonnage given by growers and sugar-company field men and in general are doubtless fairly accurate.

TABLE 1.— *Various crop rotations and their relation to the control of the sugar-beet nematode*

Rotation period and field designation	Crops used in rotation	Acre yields of beets (tons)	
		Before rotation	After rotation
1 year:			
Field No. 1	Potatoes	9.4	5.0
Field No. 2	do	13.5	16.3
Field No. 3	Wheat	11.0	9.0
Field No. 4	do	[1]	2.5
Field No. 5	do	2.5	4.0
Field No. 6	do	4.0	[1]
Field No. 7	Barley	3.5	[1]
Field No. 8	Cabbage	8.2	9.0
Field No. 9	Truck garden	5.2	4.0
	Average	6.37	5.53

[1] Total loss or so severely infested that the beets were plowed up early in the season and other crops planted.

TABLE 1.—*Various crop rotations and their relation to the control of the sugar-beet nematode*—Continued

Rotation period and field designation	Crops used in rotation	Acre yields of beets (tons)	
		Before rotation	After rotation
2 years:			
Field No. 10	Wheat, wheat	8.0	9.0
Field No. 11	do	12.0	14.3
Field No. 12	do	(1)	4.0
Field No. 13	Potatoes, potatoes	(1)	7.1
Field No. 14	do	9.0	24.5
Field No. 15	Wheat, potatoes	14.0	14.0
Field No. 16	do	14.0	12.0
Field No. 17	do	9.5	17.1
Field No. 18	Barley, potatoes	8.5	13.2
Field No. 19	Wheat, peas	(1)	11.5
Field No. 20	Peas, potatoes	7.2	11.0
Field No. 21	Potatoes, peas	9.0	11.3
Field No. 22	Alfalfa, alfalfa	(2)	(2)
Field No. 23	Wheat and sweetclover, clover plowed under for manure	(1)	12.0
	Average	7.01	12.38
3 years:			
Field No. 24	Wheat, wheat, wheat	7.2	12.1
Field No. 25	Wheat, wheat, potatoes	11.0	20.4
Field No. 26	do	10.0	17.3
Field No. 27	Wheat, nursery stock 2 years	8.5	8.0
Field No. 28	Potatoes, wheat, potatoes	12.0	13.6
Field No. 29	Potatoes 3 years	12.0	14.4
Field No. 30	Cabbage, cabbage, potatoes	7.0	8.0
Field No. 31	Wheat, potatoes, cucumbers	4.0	19.7
Field No. 32	do	4.0	21.0
Field No. 33	Wheat and alfalfa, alfalfa, potatoes	5.0	9.0
Field No. 34	Wheat and sweetclover, clover as green manure, potatoes	6.0	18.0
Field No. 35	Wheat and sweetclover, clover as green manure, corn	6.0	15.0
Field No. 36	Wheat and alfalfa, alfalfa 3 years	5.0	12.0
Field No. 37	do	12.0	17.8
Field No. 38	do	6.5	9.0
Field No. 39	do	8.5	29.3
	Average	7.79	15.29
4 years:			
Field No. 40	Wheat, wheat with sweetclover, clover plowed under for manure, potatoes.	8.0	14.0
Field No. 41	Corn, wheat, oats, and alfalfa, green alfalfa plowed under followed by potatoes.	(1)	18.1
Field No. 42	Wheat, wheat, wheat, potatoes	(1)	16.7
Field No. 43	Tomatoes, potatoes, tomatoes, potatoes	5.5	14.5
Field No. 44	Wheat and alfalfa, alfalfa 2 years	9.0	17.5
Field No. 45	do	12.0	18.4
Field No. 46	do	(1)	16.0
Field No. 47	do	5.5	13.2
Field No. 48	do	6.0	17.0
Field No. 49	do	9.0	16.0
Field No. 50	Wheat and alfalfa, alfalfa 2 years, potatoes	4.5	18.0
Field No. 51	Wheat and alfalfa, alfalfa 2 years, wheat	4.5	12.0
	Average	5.33	15.95
5 years:			
Field No. 52	Wheat and alfalfa 4 years, alfalfa	6.0	14.6
Field No. 53	Wheat and alfalfa, alfalfa 3 years, wheat	5.5	12.0
	Average	5.75	13.3
6 years:			
Field No. 54	Wheat and alfalfa, alfalfa 5 years	(1)	12.0
Field No. 55	Wheat, wheat and alfalfa, alfalfa 3 years, potatoes	9.0	16.0
	Average	4.5	14.0
7 years:			
Field No. 56	Wheat and alfalfa, alfalfa 4 years, potatoes 2 years	9.0	26.0
8 years:			
Field No. 57	Wheat and alfalfa, alfalfa 6 years, potatoes	(1)	18.5
9 years:			
Field No. 58	Wheat and alfalfa, alfalfa 6 years, wheat, corn	(1)	16.4
Field No. 59	Orchard 9 years	(1)	18.0
	Average		17.2
11 years:			
Field No. 60	Wheat 4 years, alfalfa 4 years, wheat 2 years, potatoes	7.0	14.0
Field No. 61	Wheat and alfalfa 10 years, alfalfa	12.0	18.0
	Average	9.5	16.0

[1] Total loss or so severely infested that the beets were plowed up early in the season and other crops planted.

[2] No improvement on small areas infested.

INADVISABILITY OF ATTEMPTING TWO SUCCESSIVE CROPS OF BEETS ON NEMATODE-INFESTED LAND

When a profitable crop of sugar beets is obtained on nematode-infested soil after a crop rotation, the grower will probably feel that another crop the following year should be nearly as successful. However, this is not true. A second crop invariably falls back to approximately the same yield as before the crop rotation. This is because the few nematodes remaining after the rotation have greatly increased in numbers on the first crop of beets, and these attack severely the second crop. (Figs. 14 and 15.)

Table 2 forcefully shows the results of attempting two beet crops in succession on infested land.

TABLE 2.—*Results of attempts to produce two successive crops of sugar beets after rotations on nematode-infested fields*

Rotation period (years)	Crops used in rotation	Acre yields of sugar beets (tons)	
		First crop after rotation	Second crop after rotation
4	Wheat and alfalfa, alfalfa 3 years	17.0	5.0
4	Wheat, wheat, wheat, potatoes	16.7	4.5
4	Tomatoes, potatoes, tomatoes, potatoes	14.5	5.7
3	Wheat and alfalfa, alfalfa 2 years	29.3	9.0
4	Wheat and alfalfa, alfalfa 3 years	16.0	3.0
6	Wheat and alfalfa, alfalfa 5 years	12.0	11.0
7	Wheat and alfalfa, alfalfa 4 years, potatoes 2 years	26.0	11.0
9	Orchard	18.0	10.0
	Average	18.69	7.4

CHEMICAL AGENTS INEFFECTIVE

No successful field method has been devised that will completely eradicate sugar-beet nematodes from the soil. It is true that *formalin, cyanide, chloropicrin, carbon disulfide, and other powerful poisons* will kill nematodes when they are brought in contact with them. *Users of these chemicals are cautioned that in addition to being highly poisonous, one of them, carbon disulfide, gives off a highly explosive vapor, which ignites at comparatively low temperatures. Handling of these chemicals should only be done under the direct supervision of an experienced person, and when they are stored, handled, or applied in enclosed places or where poisonous dusts are encountered gas masks and goggles should be used.*

In the many field experiments conducted with these chemicals it has been found impossible to reach all portions of the soil effectively, and a considerable number of nematodes invariably escape in the deep, unbroken subsoil and the near surface where the gases diffuse into the air. Generally only one crop is benefited by the treatment, and this does not reimburse the grower for the heavy expense involved. The following results of experiments with calcium cyanide are typical.

Calcium cyanide was disked and harrowed in at rates of 800 to 1,600 pounds to the acre. Soil examinations showed that all the nematodes to a depth of 8 inches had been killed, and at depths from 9 to 14 inches about half were dead, but below 14 inches none were killed. At the end of the season the beets from this plot had an average of 1,254 female nematodes on them.

CHEMICAL AGENTS INEFFECTIVE

No successful field method has been devised to destroy sugar-beet nematodes with chemicals. It is true that many chemicals are deadly to them, but it is impossible to obtain deep enough penetration of the soil to kill all the nematodes. Invariably a considerable number escape, and when sugar beets are planted again serious infestations develop. Usually only one crop is benefited, and this does not reimburse the grower for the heavy expense of treatment. Following are the results from experiments with sulphur and with calcium cyanide.

Sulphur was applied at the rate of 400 pounds to the acre and thoroughly disked and harrowed into the soil. On the most heavily

FIG. 14.—Typical result of attempting two successive crops of sugar beets on an infested field. After three years of alfalfa that part of the field shown at the right was plowed up and planted to sugar beets, and about 16 tons to the acre were produced. The following year the remainder of the field was broken up and the whole planted with beets. Note how definite is the division between the portion producing its first crop and that on which the second successive crop was attempted

infested areas the young beets were killed by the nematodes as usual. Where the beets managed to survive, the infestation was severe and a count revealed an average of 1,489 female nematodes on each beet. At the same time beets from check plots on which no sulphur was applied had an average of 1,282 females per beet. The yield of beets on the sulphur-treated plots was 1,260 pounds, compared with 1,230 pounds from the check plots. From the data it is evident that the sulphur had no effect in reducing the nematode infestation. In fact a careful examination of the soil after treatment indicated that no nematodes had been killed.

Calcium cyanide was disked and harrowed in at the rate of 800 to 1,600 pounds to the acre. A soil examination showed that all

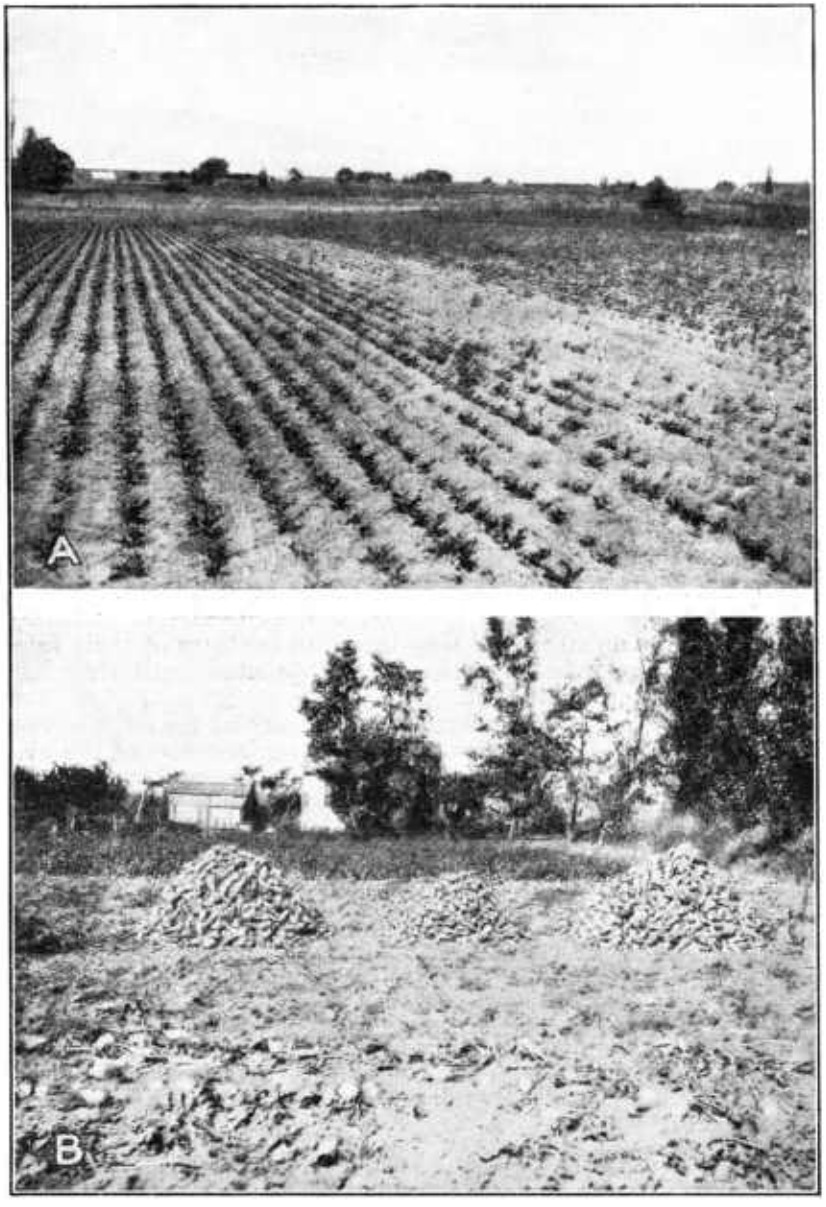

FIG. 15.—Comparison showing bad result of two successive beet crops following crop rotation on a nematode-infested field. In 1917 the sugar beets on this field were a failure because of nematode infestation. After a 3-year rotation of tomatoes, potatoes, and tomatoes, eight rows of beets were planted in 1921, with potatoes in the remainder of the field. These eight rows gave a good yield. In 1922 the entire field was planted with beets, with the result shown in *A*. The field was good except for the eight rows that had produced a previous crop of beets. At harvest time these eight rows and the eight rows on each side were harvested separately, as shown in *B*. The yield from the eight rows of the second beet crop was 881 pounds and from the rows on the right and left 2,048 and 2,480 pounds, respectively, or, computed on the acre basis, 5.65, 13.14, and 15.89 tons per acre, respectively